

Low-Loss Splices in Optical Fibers

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Several methods are reported for making splices in optical fibers. The methods have application to both liquid-core and solid-core fibers and have been demonstrated for liquid-core fibers. The lowest-loss splice consists of an inserted glass pin and an outer sleeve. Best repeatable results are 0.4 dB loss in the splice. A splicing device has been constructed which provides automatic alignment of the components and automatic assembly for several fibers at once. The technique may be directly extended to multiple splicing as for fiber cables.

I. INTRODUCTION

Several methods have been demonstrated for making splices in optical fibers. These have included fused butt joints,^{1,2} sandwiching of the fiber ends between grooved lucite blocks,^{3,4} and mounting in a snug-fitting sleeve.⁵ These techniques have been applied to multimode and single-mode fibers. The most desirable splice in an optical fiber would be one which can be made quickly and simply, causes negligible loss at the junction, and does not have a bulky connector at the junction. Furthermore, it should be made with a technique which is applicable to simultaneous splicing of a number of fibers in a bundle.

As a step toward this goal, we have constructed a splicing device which has been used to make several types of splices in multimode optical fibers. It can be used to make splices in both solid-core and liquid-core optical fibers, although we have demonstrated its use here only for liquid-core fibers. Its extension to simultaneously splicing a number of fibers is obvious and a feature to permit this has been included, although not demonstrated. Our best results, which have been obtained repeatedly, are 0.4 dB loss in the splice.

II. DESCRIPTION OF SPlicing DEVICE

The splicing device was built to be used in several different ways:

- (i) To make temporary butt joints for a number of fibers.

- (ii) To make temporary splices for a number of liquid-core fibers by simultaneously inserting transparent index-of-refraction-matched glass pins in each splice.⁶
- (iii) To make permanent splices for a number of fibers by sealing a snug-fitting glass sleeve on each splice.
- (iv) To make permanent splices for a number of liquid-core fibers by inserting glass pins and sealing on snug-fitting glass sleeves.

In all of the above applications it was intended that the device be capable of carrying out its function by aligning the ends to be spliced without any detailed alignment or separate adjustment for each fiber.

A photograph of the splicing device is shown in Fig. 1. It consists of two sliding carriers, shown in Fig. 2, which travel on snug-fitting slide bearings on precisely aligned drill rod tracks. Each of the carriers has several grooves in it into which fibers may be dropped. The cover clamp is slid in on top to hold the fibers snugly in place without crushing them.

A pan which can be slid up and down is filled with index-matching liquid. In the case of liquid-core fibers this is the core liquid. When the pan is raised up the fibers are immersed in liquid, and when it is dropped the fibers are above the liquid surface. In the center of the

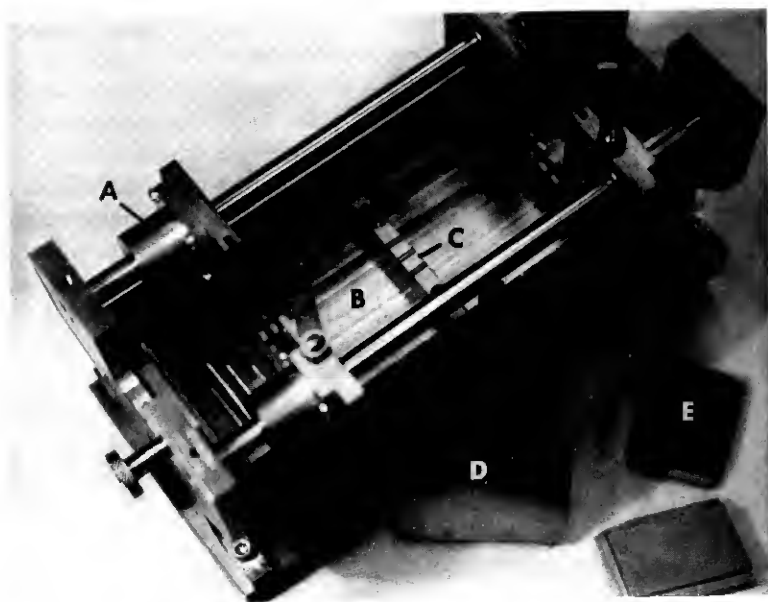


Fig. 1—Fiber splicing device. A, sliding carrier; B, immersion pan; C, pin holder; D, removable clamp for pins; E, removable clamp for fibers.

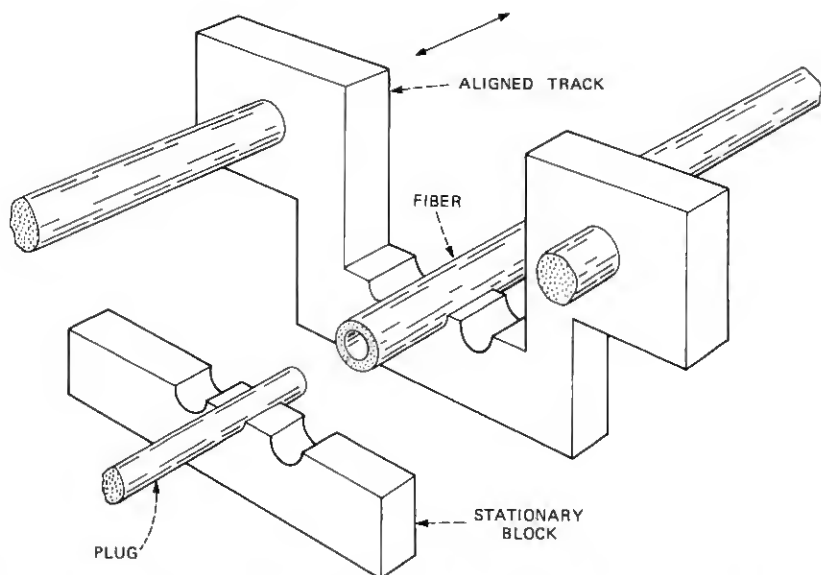


Fig. 2—Detail of fiber splicer sliding carrier and pin holder. Components are not to scale.

pan is a pedestal with grooves in it. The glass pins to be inserted into the fibers sit in these grooves and are aligned by them in such a manner that, with the pan raised to its highest position, when the two sliding carriers are brought together the pins are coaxial with the fibers to be spliced. A cover clamp is then dropped in to hold the pins in place. If pins are not used, this portion of the device is ignored. As can be seen from the construction of the device, when a splice has been completed, the spliced fiber can be lifted out of the splicing device by simply lifting off the clamps and then raising the fiber. If a number of fibers have been spliced simultaneously, each of the fibers is now an independently spliced fiber, with only a slender sleeve adding to its bulk.

III. FABRICATION OF A SPLICE

The discussion here will be given in terms of a single splice including a pin and sleeve. The two fiber ends to be joined are positioned in the aligning grooves of the sliding carriers and clamped in place. The grooves are 200 microns wide at the bottom and can be used with fibers of outside diameter of about 175 to 200 microns. An excess length of fiber is left extending from the clamp. The splice end is then obtained by scoring the fiber at the point where it is to be broken and

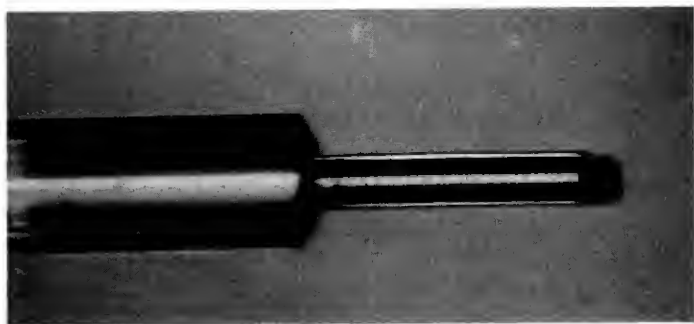


Fig. 3—Intermediate stage of splicing showing glass pin inserted into fiber core. The exposed end of the fiber is more irregular than what is used in an actual splice.

then pulling to break it. A satisfactory end is obtained in this manner, as can be seen in Fig. 3. The fiber is broken when immersed in liquid and kept immersed until the fiber has been pinned in order to avoid formation of a bubble at the junction.

The fiber pin is made from glass rod. Its index of refraction must be higher than that of the fiber cladding to provide guidance. A small index mismatch between liquid and pin will give a negligible reflection loss (a mismatch of 1 percent gives a reflection at normal incidence of 10^{-4}). However, it is better if the pin index of refraction is slightly

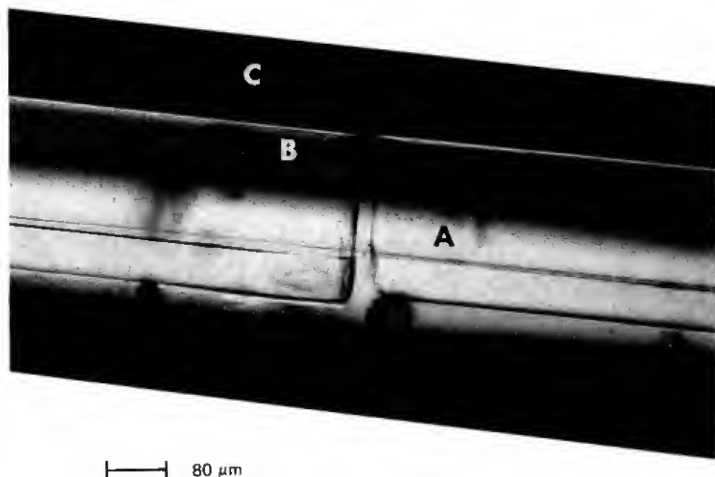
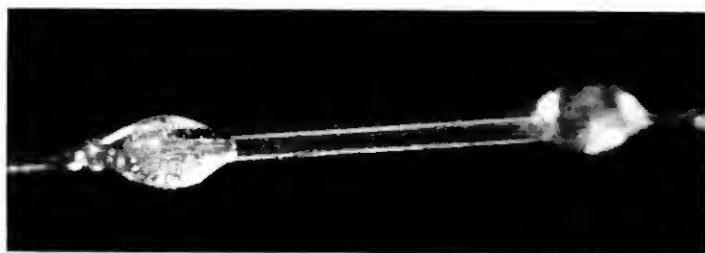


Fig. 4—Assembled splice including: A, glass pin; B, fiber cladding; C, outer sleeve.



— 1000 μ m

Fig. 5—Finished splice with epoxy-sealed sleeve.

higher rather than slightly lower than that of the liquid, since for the latter case there will be some mode conversion transferring energy to the cladding. The fibers used had a quartz cladding index of refraction, $n_D = 1.468$, and a tetrachloroethylene core, $n_D = 1.505$, and the glass plug was made from an ordinary commercial glass, $n_D = 1.52$. The pins were made by stretching the rod after softening in a flame. The core diameter of the fiber was about 100 microns, and loose-fitting cylindrical plugs of about 80 microns diameter were obtained in lengths of about 6 mm. It was found that loose-fitting plugs did not give extra loss and were easier to insert than tight-fitting plugs. (Any attempt to make a permanent splice by jamming a plug into the fiber ends was abandoned because the fiber broke from the pressure of the plug.) Furthermore, keeping the plugs undersized avoids the necessity for making them tapered. The plugs were cleaned with "Windex D"* before using. The pin was placed on the center pedestal of the splicing device and clamped in place. The two sliding carriers were then brought together and the pin entered both fiber ends.

Due to a small amount of residual play and misalignment (≈ 25 microns) it was necessary to manipulate the device slightly in order to insert the pin. It is this limitation which prevents the making of simultaneous splices. Further shop work should eliminate the residual errors. Figure 3 shows a pin which has been inserted into a fiber.

The outside sleeve is made of glass. Its composition and optical quality are unimportant, and other materials could be used. The sleeve is made by stretching glass tubing after softening in a flame.

A length of this tubing is slipped over one of the fiber ends and slid out of the way but kept between the sliding carriers before insertion of the fiber end in the splicing device. When the pin connection has

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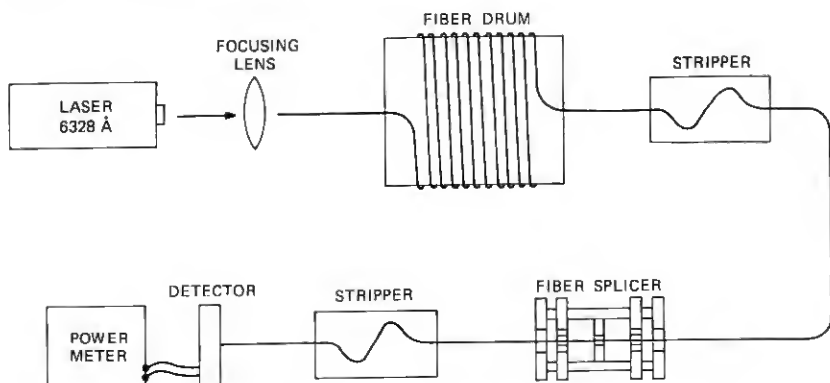


Fig. 6—Test setup for measuring splice loss.

been completed, the sleeve is slid over the splice, and then the outer clamp and the clamp on the sliding carrier blocking the sleeve are removed. The third clamp is then removed and the completed but unsealed splice is lifted out. The splice at this stage is shown in Fig. 4. The final step is to seal the sleeve onto the fiber. This is done by placing a drop of quick-curing epoxy at each end of the sleeve. The epoxy consists of equal parts of Shell Epon 828* and Minit-Cure† hardener. It cures in several minutes. The completed splice is shown in Fig. 5.

IV. MEASUREMENT OF SPLICE LOSS

The test setup used to measure the loss due to the splice is shown in Fig. 6. Light from a He-Ne laser at 6328 Å is injected into the fiber. Since, as is to be expected, the loss in the splice is mode-dependent, a realistic measurement is obtained only for a mode distribution characteristic of that existing in the fiber in its "steady state," i.e., a long distance from the beginning of the fiber, such that the mode distribution is independent of light-launching conditions. Therefore, the splices were made after about 100 m of fiber since previous measurements have shown that the steady-state condition has been obtained. Furthermore, it is necessary to strip cladding energy both before and after the fiber.

Splice loss was then obtained by measuring the fiber output without a splice and comparing it with the output with an intervening splice.

V. RESULTS

In Table I we summarize results obtained for a simple butt joint and two types of permanent splices. It can be seen that the best results

* Manufactured by Shell Petroleum Co., New York.

† Manufactured by Allaco Products, Inc., Braintree, Massachusetts.

TABLE I—SPLICING LOSS OBTAINED FOR VARIOUS TYPES OF SPLICES

Method	Two fiber ends with no plug (butt joint)	Two fiber ends aligned by an outer glass sleeve	Two fiber ends aligned with a plug and outer sleeve
Average results	1.8 dB	1.2 dB	0.53 dB (19 splices)
Best results	0.86 dB	0.70 dB	0.40 dB (6 splices)

are obtained using a plug and sleeve combination. The best results of 0.40 dB are repeatable, and compare favorably with other reported techniques. They are slightly better than any reported for multimode fibers, and are exceeded only by Someda's best results for single-mode fibers.⁴ While Someda's technique presumably should give as good or better results for multimode fibers, this has not actually been demonstrated.

The epoxied splices have been found to be quite strong and, under tension, are stronger than the fiber itself which will break first when stretched. The splices have been observed over several weeks with no observable increase in loss.

VI. SUMMARY

A simple mechanical device has been constructed and used to make splices in liquid-core optical fibers. This device is also suitable for splicing solid-core fibers. The device makes a prealigned splice consisting of a transparent glass plug and an outside sealed-on sleeve. Repeatable results of 0.4 dB loss have been obtained. These compare favorably with other reported results. The device may also be used to make splices either with the outer sleeve or pin alone. However, in either case the losses are higher. The method is directly extendable to making multiple splices as, for example, in a cable. The resultant splices are compact and independent of each other.

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